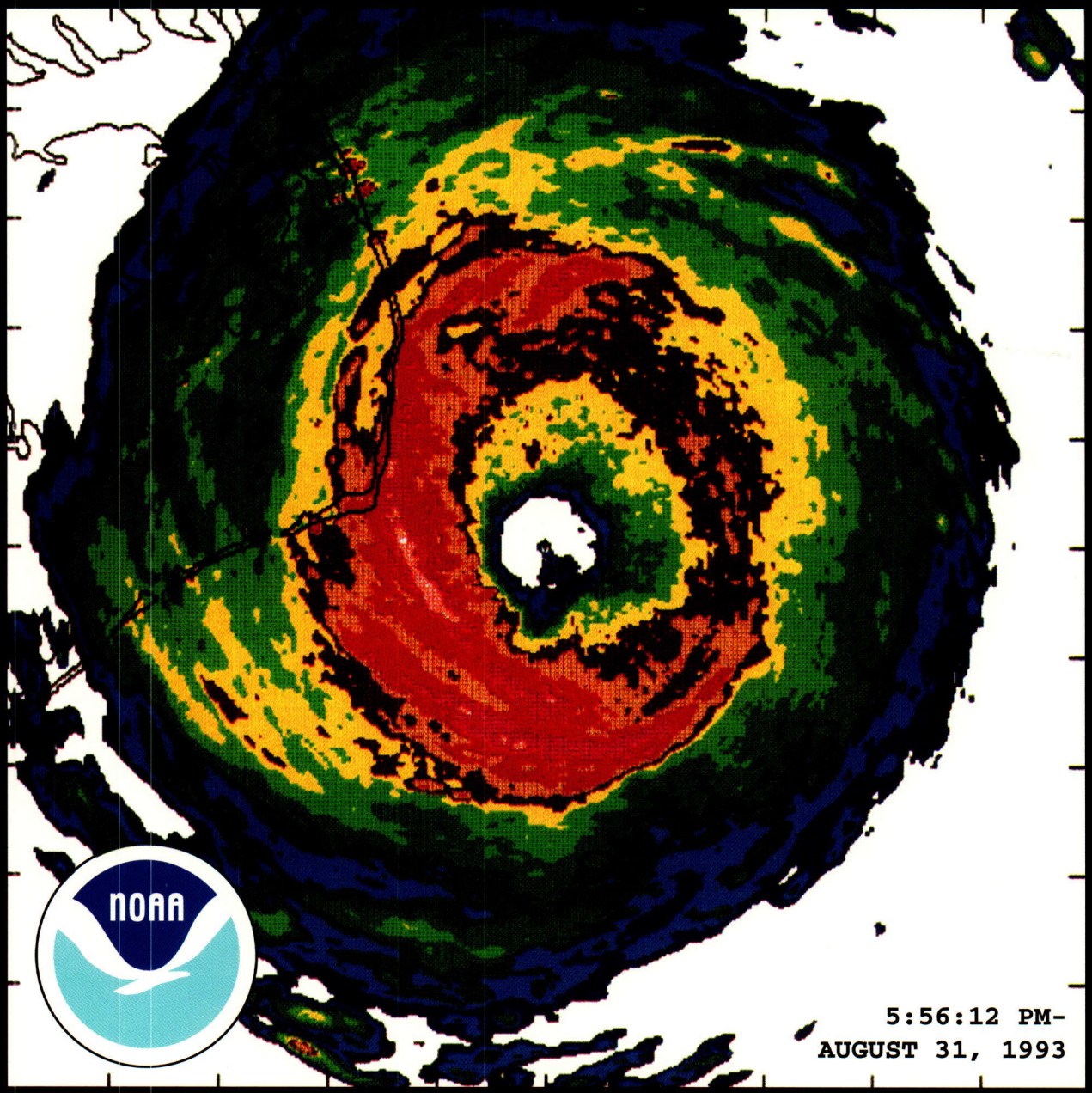
HURRICANE EMILY ASSESSMENT



Review of hurricane evacuation studies utilization and information dissemination

US Army Corps of Engineers

FEDERAL EMERGENCY MANAGEMENT AGENCY

HURRICANE EMILY ASSESSMENT
Review of Hurricane Evacuation Studies Utilization and Information Dissemination

Prepared for

U.S. Army Corps of Engineers
and
Federal Emergency Management Agency

Prepared by

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Tallahassee, Florida 32301

June 1994

09-716.00

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SECTION 1
INTRODUCTION

On Tuesday, August 31, 1993, Hurricane Emily passed just east of Hatteras Island, North Carolina. The storm, which was the most devastating hurricane that Hatteras Island residents had seen in recent memory, was a Saffir-Simpson Category 3 hurricane with peak winds at approximately 107 mph. With sound water levels at 10-1/2 feet above normal, the hurricane was an eye-opener and exceeded all expectations of flooding that could occur on the backside of a barrier island due to a hurricane of this intensity. Damage estimates were approximately 13 million dollars in the immediate impact area with over 3 million in damages to Cape Hatteras School alone.

Prior to Hurricane Emily, a comprehensive hurricane evacuation study had been completed for eastern North Carolina in 1987. The preparation of the hurricane evacuation study was a cooperative effort between the US Army Corps of Engineers, Wilmington District, the State of North Carolina, Division of Emergency Management and FEMA. The study involved eighteen counties along the open coast and inland sounds of the eastern North Carolina region. Corps of engineers staff served as study managers for the effort with major logistical support provided by State EM staff.

Since Emily directly affected areas where previous study data was available, there were several key questions which needed to be addressed:

- Did local and state officials use any of the data already produced in Corps/FEMA studies?
- Were study data and products regarding storm hazards, shelter information, evacuation clearance time, and decision making accurate and reliable?
- What Emily data is available that might be relevant to a future FEMA/Corps/State of North Carolina study update?

To answer these questions a study team comprised of William Massey representing FEMA, Al Bjorkquist representing the Wilmington District of the U.S. Army Corps of Engineers, and Will Brothers, Doug Hoell, and Steve Glenn representing the State of North Carolina, Division of Emergency Management visited the local officials along the North Carolina Coast. Don Lewis of Post, Buckley, Schuh & Jernigan, Inc. accompanied the study team and documented all relevant findings. Major technical contributions to the effort were provided by Wallace DeMaurice of the National Weather Service through his Hurricane Emily Post Storm Report and by Brian Jarvinen of the National Hurricane Center through his Comparison of Observed and SLOSH Model Calculated Storm Surge in Hurricane Emily report. A list of those indviduals who attended local coordination meetings is included in Appendix A. (Photos at the conclusion of this introduction show scenes from the meetings.)

Discussion with local emergency management officials focused on facts regarding the evacuation, study products that might have impacted the evacuation decision process, traffic control and clearance, sheltering and public information. Discussions also addressed the types of material and public information communities could have used that had not been delivered to them as of the arrival of Hurricane Emily.

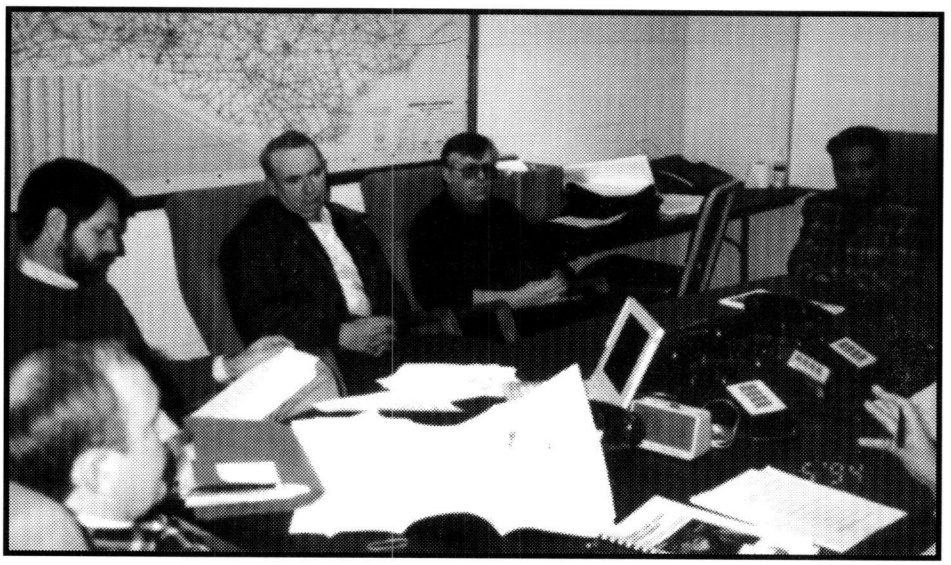
Unlike some previous post-storm assessments, this effort did not include a residential behavioral survey to gauge actual response. It is anticipated that a significant behavioral analysis will be a part of an upcoming hurricane evacuation re-study for the North Carolina coastal areas. This major effort will gauge Emily response and will suggest behavioral response parameters which should be used for planning purposes.

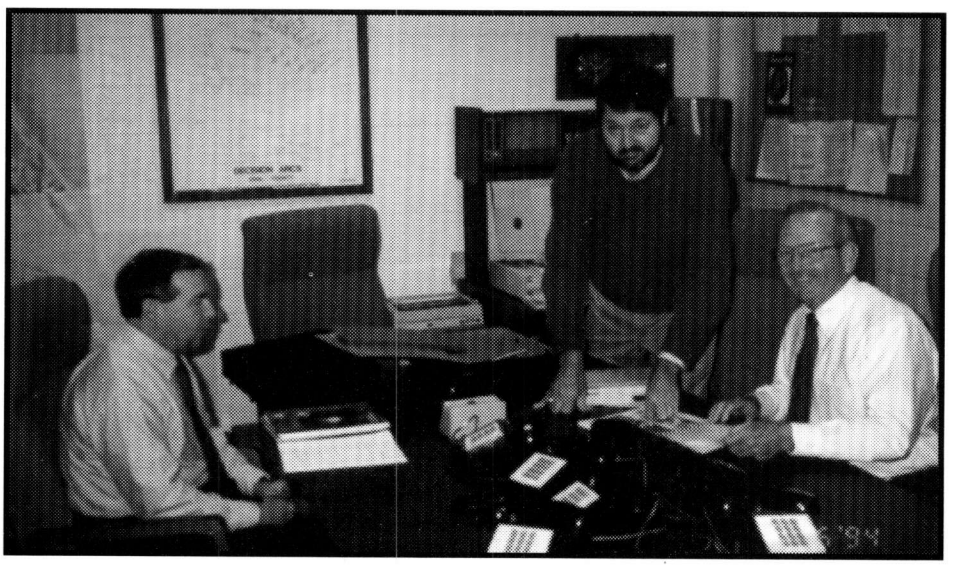
It should also be noted that due to funding constraints, this effort/report focused only on the North Carolina and to a very limited degree, the southeastern Virginia affected areas. In reality, many areas from Florida to New York were on alert for Hurricane Emily. Some evacuation took place on Long Island (from Fire Island) New York which is very important and encouraging to note given the vulnerability of residents and past difficulties in evacuating that barrier island.

This report documents the major findings of the study team and is organized by general category of hurricane evacuation analysis. Those general categories that are addressed include:

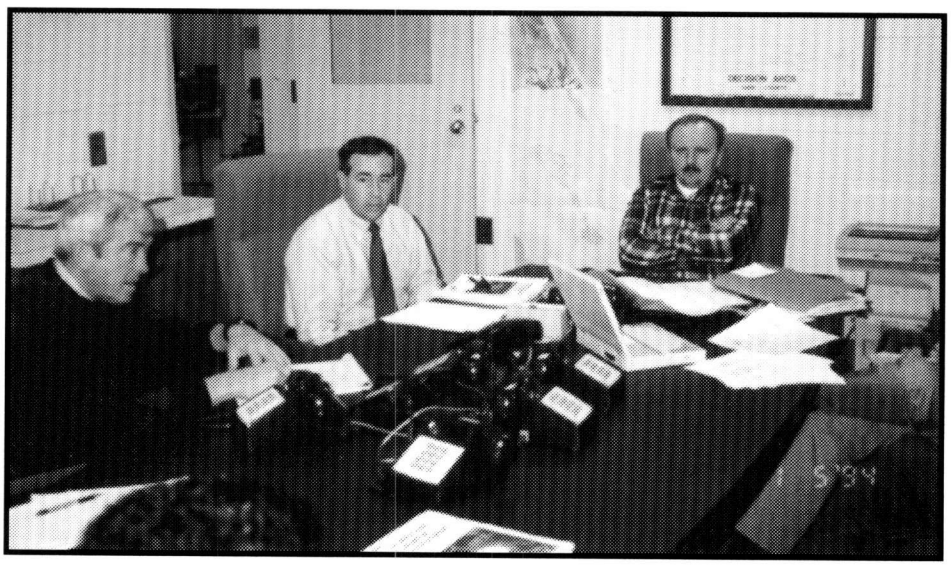
- Hazards/Vulnerability Data
- Public Sheltering
- Transportation Clearance Time Data
- Evacuation Decision Making and Public Notification/Information.

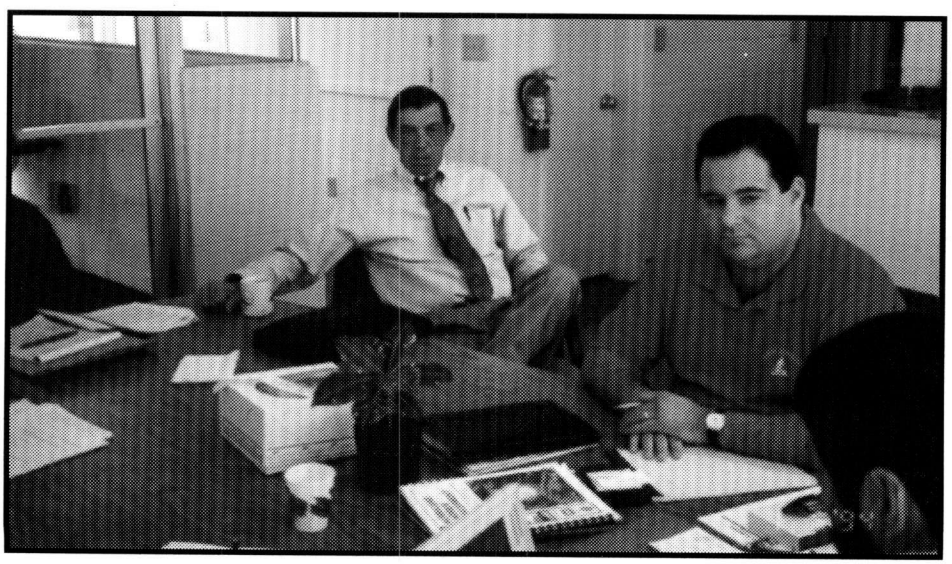
Representative Scenes at Local Coordination Meetings





Representative Scenes at Local Coordination Meetings





Representative Scenes at Local Coordination Meetings

SECTION 2

HAZARDS/VULNERABILITY DATA

In FEMA/Corps of Engineers comprehensive evacuation studies, the primary objective of the hazards analysis is to determine the probable worst-case effects for the various intensities of hurricanes that could strike an area. Specifically, a hazards analysis quantifies and maps the expected hurricane-caused coastal inundation that would require emergency evacuation of the vulnerable population. One of the first hazards analysis products of the Eastern North Carolina Hurricane Evacuation Study was an atlas showing the inland extent of surge flooding expected for various intensities based on SLOSH model runs conducted at the National Hurricane Center. Storm surge heights used in that atlas were the maximum value that one would expect for hurricanes of any probable direction and forward speed. However, Hurricane Emily produced surge heights on the backside of the barrier island that exceeded previous SLOSH model values.

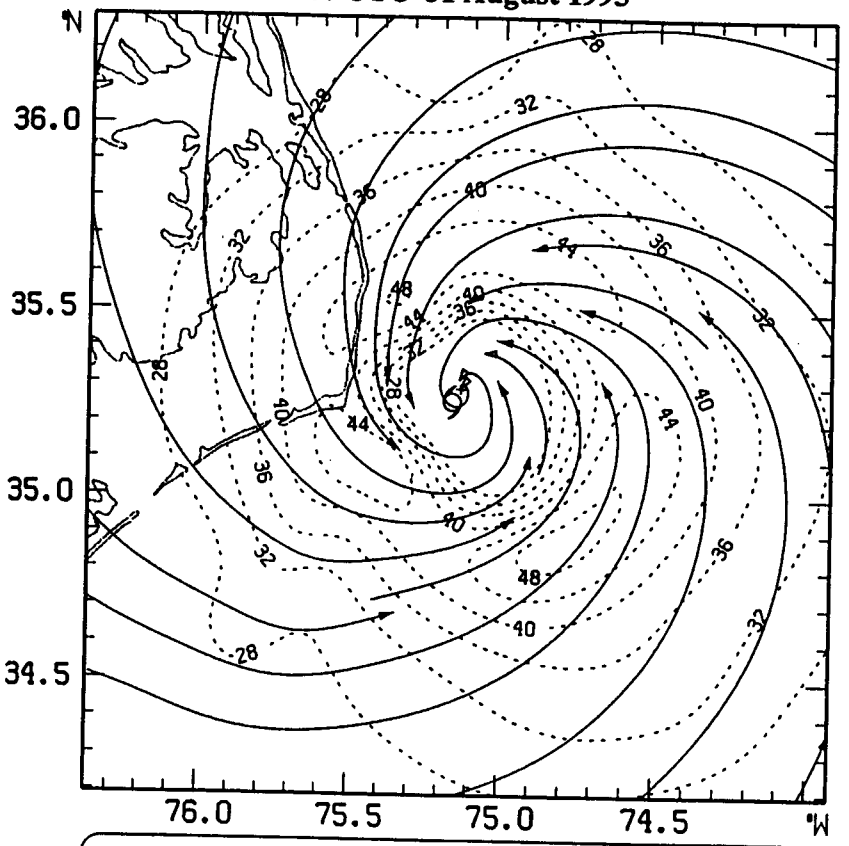
A comparison of observed and SLOSH model calculated storm surge for Hurricane Emily was performed by Brian Jarvinen, chief of storm surge group with the National Hurricane Center. A portion of this report provides the explanation as follows:

> Strong winds ahead of the center generated storm surge and breaking waves on the Atlantic shoreline of the Outer Banks. The Atlantic generated storm surge and breaking waves did not penetrate beyond the Atlantic shoreline dunes except in low dune areas or locations where man made openings in the dune line existed. As the hurricane moved abeam of Cape Hatteras, strong winds on the left or west side of the hurricane, blowing from the north and northwest drove Pamlico Sound water southward and southeastward and piled it up against the Sound side shorelines of Hatteras and Okracoke Islands.
>
> Members of NOAA's Hurricane Research Division made an analysis of the maximum 10-min sustained winds near the surface when Emily was abeam of Cape Hatteras. Figure 1 is a composite of wind data made from wind recording anemometers near the surface and aircraft reconnaissance wind data reduced to the surface. Winds before and after the 2200 UTC (Subtract 4 hours to obtain EDT) time were used in the composite. The solid lines are streamlines and the wind is blowing parallel to them. The dashed lines are wind speed in meters/second (double these values to obtain knots).

Hurricane Emily - HRD Analyzed Wind

Maximum 10-min Sustained Winds (m s^{-1})

2200 UTC 31 August 1993



Streamlines and Isotachs (Contour Interval = 4 m s^{-1})

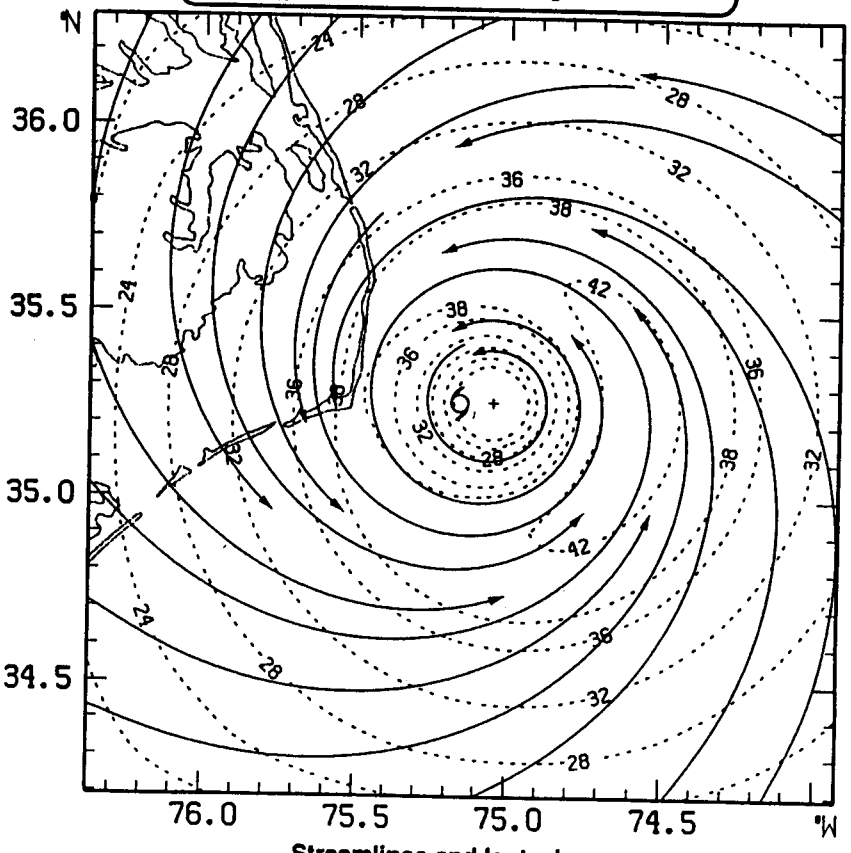
Hurricane Research Division / NOAA

Hurricane Emily - SLOSH Wind Model

2200 UTC 31 August 1993 (wind speeds units =m s^{-1})

Lat = 35.26°N, delta P = 55 mb,

R_{MAX} = 41.8 km, Forward Spd. = 5.4 m s^{-1}



Streamlines and Isotachs

(Contour Interval = Varies from 2 to 4 m s^{-1})

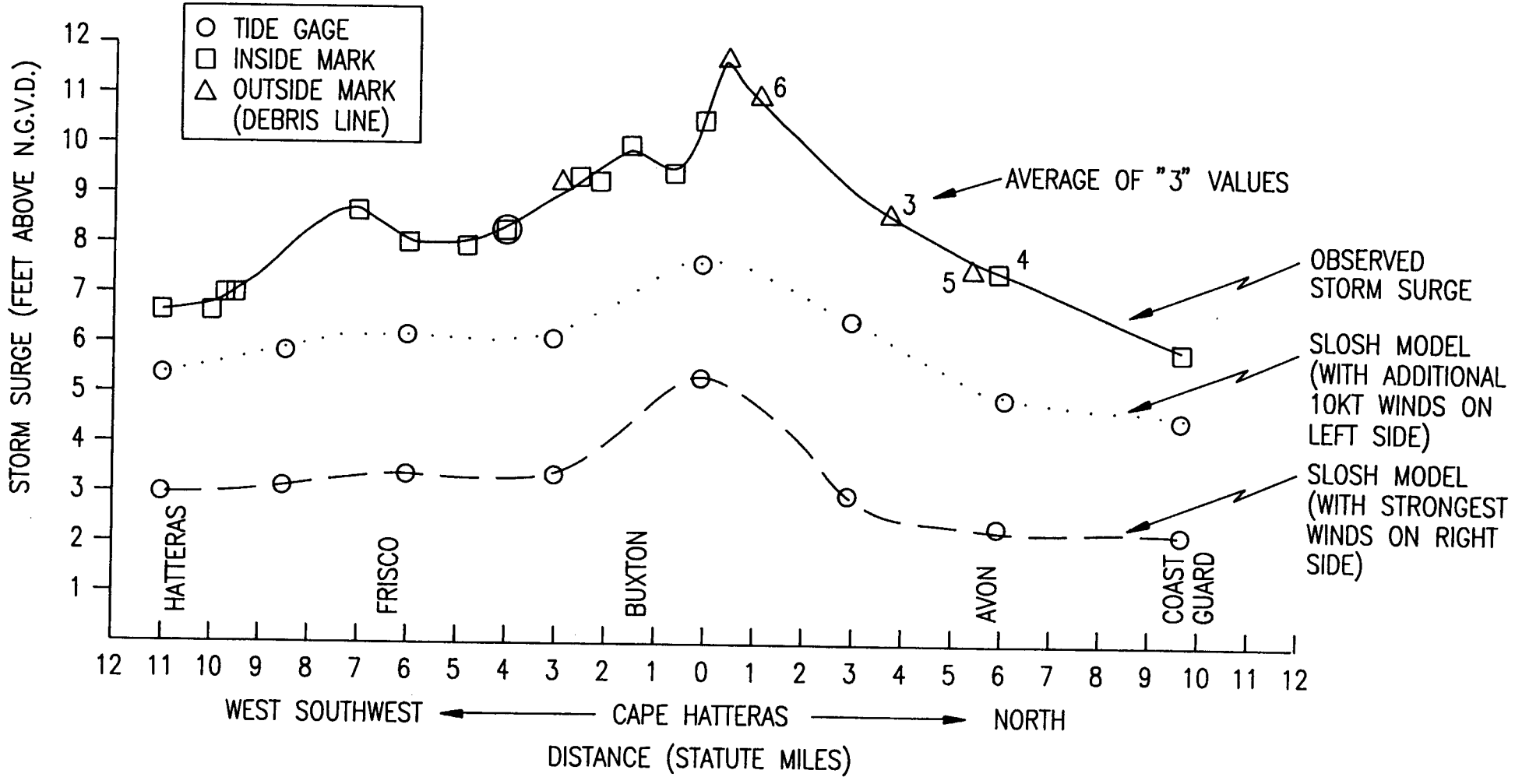
The flow of air toward the center with increasing wind speed is a typical feature of hurricanes. Another feature generally observed is for the maximum winds to be on the right side of the hurricane relative to the direction of motion. However, in Emily there are strong winds on both the left and right sides. The strong wind on the left side of the hurricane had a major effect in storm surge generation in Pamlico Sound. The north to northwest flow in Pamlico Sound with wind speeds of 43 to 45 m/s near Cape Hatteras can be seen in Figure 1. These strong winds combined with the slow forward speed (i.e., 10-12 mph) of Emily, caused extensive flooding across the island and left debris lines on the back side of the sand dunes on the Atlantic shoreline.

After the hurricane, a highwater mark survey was conducted by the Raleigh North Carolina office of the U.S. Geological Survey. The survey was confined to the lower part of Hatteras Island. All of the high water marks were referenced to the National Geodetic Vertical Datum (NGVD), which is where mean sea level was in 1929. Where possible the marks were recorded inside of closed buildings to give a "still water"' elevation. In remote locations outside marks and debris lines were used. Figure 2 shows a plot of the highest marks observed. The values start near the town of Hatteras and go eastnortheastward and then northward to the Coast Guard Station. The maximum inside and outside marks were recorded near each other and were 10.5 and 11.5 feet above NGVD respectively. Note that these two highest values were recorded in the location where Hatteras Island makes a right angle.

Also, recorded on Figure 2 is the storm surge profile on the Sound side calculated by the SLOSH model using Emily best track information. It is apparent that the SLOSH model under-estimated the water heights by approximately 4-6 feet. This is unusual because the SLOSH model generally has an accuracy of plus or minus 20 percent. Figure 1 suggests one explanation for this large error. The observed winds on the west side of Emily seem to be stronger than normal. Figure 1 includes the wind field generated by the SLOSH model at 2200 UTSC. Comparison of wind speeds on the west side of the eye in Figure 1 show an approximate 6 m/s difference or about 12 knots. The SLOSH model was re-run forcing a stronger wind speed of about 10 knots on the west side. The dotted line in Figure 2 represents the SLOSH model storm surge profile with this 10 knot adjustment. An increase of approximately 2.5 feet has been made in the calculated storm surge. However this still does not meet the SLOSH error criteria. Since the observed wind data analysis is still preliminary, it is possible that the wind speeds over the Sound may be higher than those in the top half of Figure 1. Also, the difference in direction of flow on the left side relative to the Sound side shoreline may play a role.

It should be noted that the SLOSH model comparisons with observed data in hurricanes Hugo and Andrew were within the model error range. Maximum storm surge in both these major hurricanes occurred on the right side. It appears that generation of large storm surges on the left side of the hurricane on the "back side" of islands is limited to Pamlico Sound and the Florida Keys. Consideration of this strong wind on the left side of a hurricane will need to be dealt with in future SLOSH studies in these two locations.

OBSERVED AND SLOSH CALCULATED STORM SURGE FOR
HURRICANE EMILY, 31 AUGUST 1993
ELEVATIONS REPRESENT FLOODING CAUSED BY PAMLICO SOUND
WIND DRIVEN WATER.
*NOTE: OBSERVED HEIGHTS ARE PRELIMINARY AND ARE FROM
U.S. GEOLOGICAL SURVEY, RALEIGH, NC.



The Albemarle/Pamlico SLOSH modeling studies conducted for the North Carolina Hurricane Evaucation Restudy will incorporate the findings from the Emily analysis and will also address surge heights that result from a fast moving hurricane (35 mph forward speed). A new surge atlas will be produced for the North Carolina coast and will be the first product of the re-study.

SECTION 3
PUBLIC SHELTERING

The primary objectives of shelter analyses prepared for FEMA/Corps comprehensive hurricane evacuation studies are to list public shelter locations, assess their vulnerability relative to storm surge flooding, and to estimate the number of people who would seek local public shelter for a particular hurricane intensity or threat. Shelter location/capacity data are obtained from local emergency management staff working in conjunction with the American Red Cross, schoolboard or other local agencies. Comparisons are then made with surge modeling data to assess the flooding potential. Public shelter capacity is usually compared to public shelter demand figures generated in the transportation analysis to determine potential defects or surpluses in sheltering. Behavioral assumptions for the transportation analysis regarding the percent of evacuees going to public shelter come from the behavioral analysis or behavior parameters recommended by the local emergency management directors.

Shelter issues related to Emily were discussed with local officials. Discussions focused on the following topics:

- When were shelters opened and when did evacuees arrive/stop arriving?
- How many people were sheltered and how many shelters opened?
- Were any problems encountered with shelters during the storm?

In general, public shelters played a very minor role in the evacuation for Hurricane Emily. Few shelters were opened and few evacuees went to public shelters. Some possible reasons for this include:

- except for Dare County, participation in the evacuation for Emily was very limited.

- information concerning inland shelters and their availability was difficult to communicate to coastal evacuees.

- most evacuees went to inland hotels or friends' and relatives' homes.

- due to recent Red Cross policies, no official shelters were opened in Dare, Currituck or Tyrrell Counties.

- Emily's track allowed many counties to avoid a significant evacuation.

A summary by jurisdiction of public shelter openings and use is provided as follows:

Dare County -	no Red Cross shelters; 3 county refuges opened; most Dare public shelter evacuees went to Elizabeth City and Williamston
Camden/Pasquotank Counties -	4 shelters opened in Elizabeth City; open 2 nights; 500 people sheltered; 75% of evacuees from Dare County
Currituck County -	no shelters opened
Tyrrell County -	no shelters opened
Martin County -	3 shelters opened; 800 people sheltered; shelters open for two days; no local public shelter evacuees
Chowan County -	2 shelters opened; 60 people sheltered; 1 shelter open 2 nights; half local evacuees and half from other counties
Bertie County -	1 shelter opened for six hours; no evacuees
Washington County -	3 shelters opened; 70 people sheltered most of which were Tyrrell County evacuees; shelters open 1-1/2 days
Pamlico County -	1 shelter opened at 7 am the 31st (day of storm). 30 people sheltered all of which were locals; shelter opened 12 hours
Carteret County -	6 shelters opened (4 Red Cross, 2 county); 200 people sheltered; opened Monday the 30th at 3 pm

Craven County -	6 shelters opened early Tuesday AM; 100 local evacuees sheltered; shelters manned by DSS personnel; recreation kits provided to children; some kennel facilities made available for pets
Pender County -	1 shelter opened; 16 evacuees sheltered; opened 7 am Tuesday the 31st/closed 3 pm
Onslow County -	opened Dixon Middle School on Monday the 30th at 4 pm; no evacuees; opened Swansboro Middle School on Tuesday at 8 am; 6 people sheltered
New Hanover County -	no shelters opened; had one shelter on standby
Brunswick County -	no shelters opened
Virginia Beach, VA -	5 shelters opened; 500 people sheltered; opened 4 pm Tuesday the 31st/ closed 7 am next day

Despite the limited opening and use of public shelters, Emily pointed out the need for more public shelter coordination between coastal and inland counties. Mutual agreements need to be worked out between local jurisdictions and a communications system must be in place to advise the evacuating public as to shelter options. The restudy of the North Carolina coast will need to take a careful look at this issue as well as inland public shelter strategies and their effect on clearance times. Public shelter evacuee destination percentages may have to be adjusted downward depending on expected sheltering capability. Other post-storm assessments have pointed out the need for significant inland shelter planning in every state where coastal evacuees cannot be sheltered in the coastal counties. Some counties are wrestling with special needs evacuee issues - this problem may be further complicated by the American Disabilities Act which may prohibit the exclusive designation of "special needs shelters."

SECTION 4

TRANSPORTATION CLEARANCE TIME DATA

In FEMA/Corps comprehensive hurricane evacuation studies, the primary objective of the transportation analysis is to determine the clearance times needed to conduct a safe and timely evacuation for a range of hurricane threats. Information from the hazards, vulnerability, shelter, and behavioral analyses as well as various sources of permanent and seasonal population data are direct inputs to the transportation analysis. For the 1984-1987 North Carolina study, clearance times were developed for three response levels of evacuation and stratified by levels of seasonal occupancy occurring at the time of a hurricane evacuation.

Discussions with local officials in eastern North Carolina focused on transportation data related to the Emily evacuation. Where a comparable evacuation occurred, study produced data were compared to actual Emily data and revolved around responses to these questions:

- Was the evacuation roadway network accurate - did evacuees use projected travel routes?
- Were any traffic control actions taken to speed up flow?
- When was the evacuation essentially completed and how long did the evacuation take?
- Were any major traffic problems encountered in this evacuation?

Many counties were able to avoid carrying out a significant evacuation due to low clearance time requirements and storm track information which showed the storm moving away from threatened areas. However, several counties in North Carolina did experience a significant evacuation. Information relating to transportation clearance for those counties is provided as follows:

Dare County- 50% of permanent residents left/90% of seasonal visitors (estimated total of 120,000 people evacuated); 10 hours to evacuate and clear roadways on Monday the 30th; highway patrol provided major assistance; one-waying of US 158 (Wright

Memorial Bridge) worked well; traffic cleared early Tuesday AM through Camden and Pasquotank Counties; (study calculated time of 10-1/2 to 12 hours).

Tyrrell County - Mandatory evacuation Tuesday AM the 31st - voluntary evacuation day before; 4 hours to clear local evacuees; DOT changed traffic signals on US 64 to stay green longer for westbound movements; (study calculated time of 6-1/2 hours).

Currituck County - Evacuation of Outer Banks, mobile homes and low lying areas accomplished - no clearance time data.

Martin County - US 17/US 64 intersection in Williamston not as bad as anticipated.

Pamlico County - Voluntary evacuation of low lying areas started 6 am Tuesday the 31st, completed by 11: am; 1500 to 2000 people evacuated; 5 hours to clear evacuees; (study calculated time of 6 hours).

Carteret County - 50% of permanent population on Bogue Banks participated, no more than 25,000 seasonal residents present due to school starting; asked seasonal residents to leave Monday am the 30th; traffic lights on blink - police changed signals in Havelock (Craven County) to give more green time to US 70; by Tuesday traffic cleared.

Pender County - Mandatory evacuation of Topsoil Beach at 7 am Tuesday the 31st; recommended evacuation of everything east of US 17; evacuation complete at 1 pm; 6 hours to clear evacuees (study calculated time of 6 hours).

In Wallace DeMaurices's Hurricane Emily Post Storm Report prepared for the Cape Hatteras, N.C. National Weather Service Office, this account of the Dare County, Currituck County, and Hyde County (Ocracoke Island) evacuation was provided:

> "Evacuation effort for all of Coastal Northeast North Carolina was accomplished in text book fashion. Mandatory evacuation began for Ocracoke Island Sunday, August 30, and at 630 AM Monday for all of Dare County and outer banks portion of Currituck County later in the day. By early morning Tuesday an estimated 120,000 tourists and locals had heeded the call to move inland over highway 158 and 64 or by ferry from Ocracoke. The estimated number remaining in the hardest hit areas was about one thousand on Hatteras Island and around six hundred on Ocracoke Island."

Despite this glowing account of the Emily evacuation, it is important that a future restudy of the North Carolina coast take into account increased population, roadway changes (such as I-40 out of Wilmington), and larger hazards area due to potentially higher surge levels. The transportation analysis for the restudy should also look at critical intersections and interchanges in inland regions of North Carolina (e.g., Goldsboro) where evacuation traffic congestion can occur.

SECTION 5

EVACUATION DECISION MAKING AND PUBLIC INFORMATION/NOTIFICATION

Some of the most important products developed as part of the Atlantic and Gulf Coast FEMA/Corps hurricane evacuation studies and delivered to local and state officials have been evacuation decision making tools. These tools are decision arc maps and tables as well as computer software such as HURREVAC. Products such as these graphically tie together real-time storm characteristics with clearance time data. Their purpose is to give emergency management directors a means of retrieving Technical Data Report information without having to dig through a report during an emergency. Evacuation decision tools provide guidance and assistance to decision makers as to when an evacuation should begin relative to a specific hurricane, its associated wind field, forward speed, probabilities, forecast track, and intensity.

For the Hurricane Emily threat, most counties in North Carolina used HURREVAC and were very pleased with its performance. Decision arcs were used as well. GDS (Geographic Decision System by Hazards Management Group) was used by the City of Virginia Beach and performed well for them. Much of the data concerning the storm was received form the Weather Channel broadcasts and faxed weather communications from the State's Area A and C emergency management office. Other tools included NOAA radio, NAWAS (National Warning System), and flood inundation maps provided through the Corps FEMA study completed in the mid 1980s. More counties would like to have NAWAS. New storm surge maps are needed which will be colorized and will show new SLOSH inundation data. Some counties would like mapping at a larger, easier to read scale.

In terms of public information, the following means of communicating preparedness notices were used:

Television - including The Weather Channel overrides (EINS Emergency Information Notification System)
Radios
EBS (Emergency Broadcast System)

Area A & C Office PIO press releases
Door-to-door notification in Hatteras, south Nags Head, Tyrrell, Washington (mobile homes) and Pamlico Counties
State of North Carolina information materials/brochures
Video tapes - prerecorded
local paper supplements
phone book information
Public Service Announcements - pre recorded for TV and radio
Civic Group briefings in off-season

Local officials in some areas would like additional public information/media materials that show people how to protect their homes and that show elderly what to do as a hurricane approaches. Inland wind warning information would be helpful to inland counties. For North Carolina, more thought needs to be given regarding the description of evacuation areas/zones to the public. The use of the term "low lying areas" is not descriptive enough and relies on the public to understand their surge vulnerability.

APPENDIX A

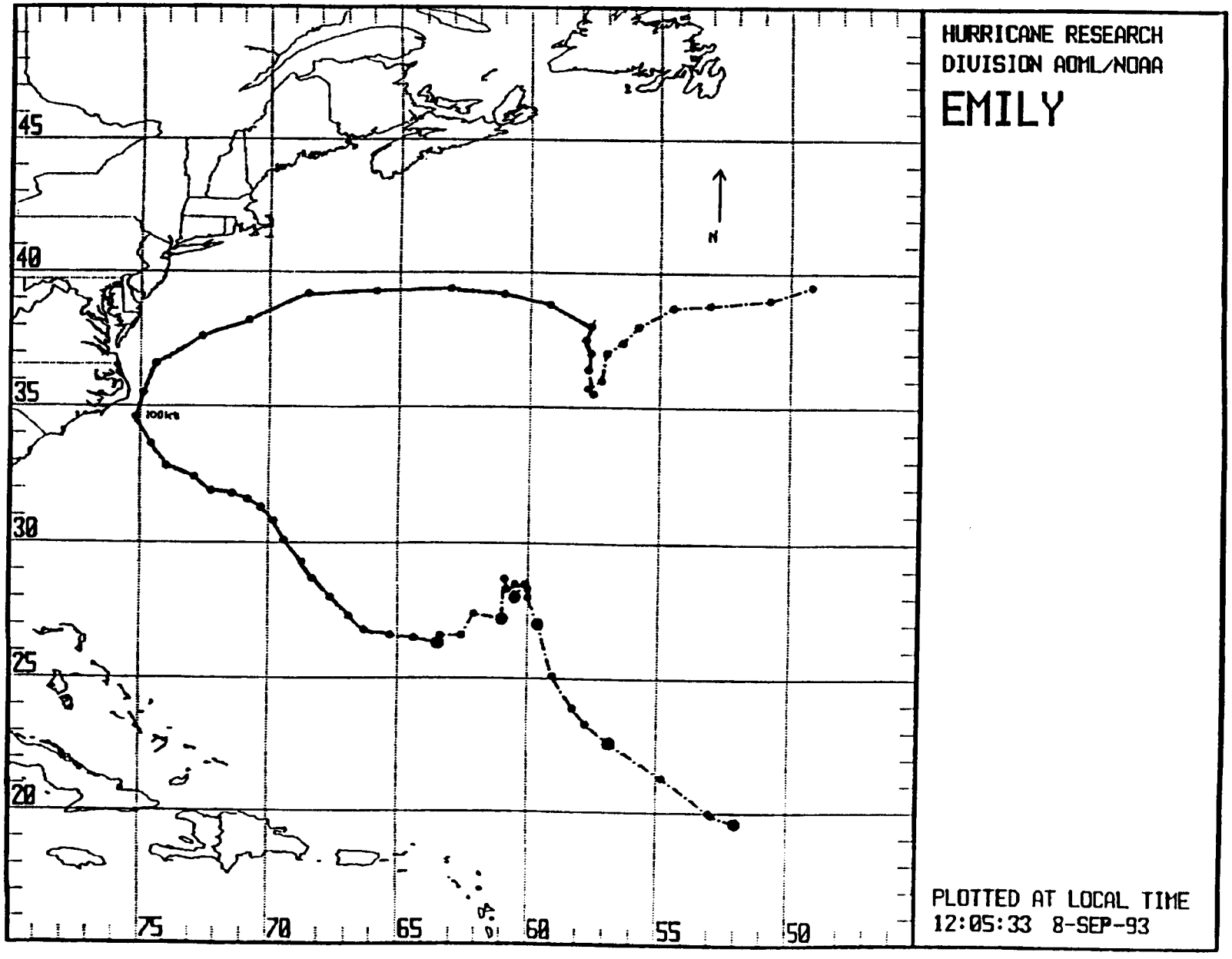
Meeting Attendees/Persons Providing Assessment Input

Study Participants/Meeting Attendees

Clarence Skinner	Dare County
Sandy Sanderson	Dare County
Judy Payment	Currituck County
Cheryl Booth	Dare County
Bob Fraser	Camden/Pasquotank Counties
Buddy Swain	Tyrrell County
Andy Willis	Pamlico County
Wallace DeMaurice	National Weather Service
Dale Lilly	Martin County
Billy Smith	Bertie County
Doug Belch	Chowan County
Ann Keyes	Washington County
Al Hadley	Carteret County
Mike Adderton	Carteret County
Henry Sermons	Craven County
Twig Rollins	Pender County
Don Herman	Onslow County
Karen Wagley	Onslow County
Dan Summers	New Hanover County
Cecil Logan	Brunswick County
Mark Marchbank	City of Virginia Beach
Steve Glenn	Area "C" State Emergency Preparedness Office
Doug Hoell	Area "A" State Emergency Preparedness Office
Will Brothers	State Emergency Management Office
Bill Massey	FEMA, Region IV
Al Bjorkquist	U.S. Army Corps of Engineers Wilmington District
Don Lewis	Post, Buckley, Schuh & Jergnigan, Inc.
Brian Jarvinen	National Hurricane Center

APPENDIX B

Hurricane Emily Track


HURRICANE RESEARCH
DIVISION AOML/NOAA
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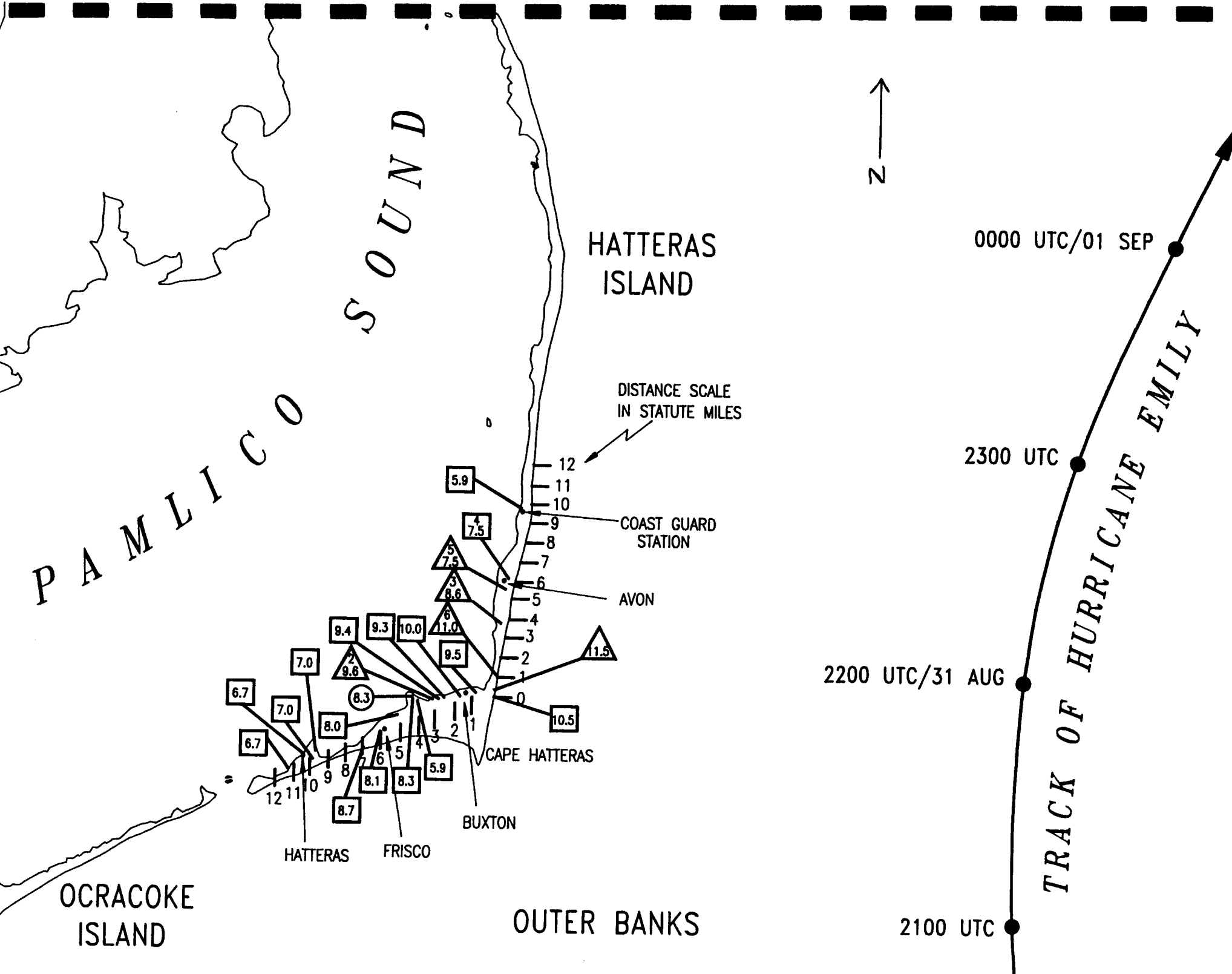
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DISTANCE SCALE IN STATUTE MILES
COAST GUARD STATION
AVON
CAPE HATTERAS
BUXTON
FRISCO
HATTERAS
OCRACOKE ISLAND
OUTER BANKS

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